TEST REPORT

Hemyc (1-Hour) Electrical Raceway Fire Barrier Systems Performance Testing

Cable Tray, Cable Air Drop and Junction Box Raceways

Project No. 14790-123264

FINAL REPORT

April 18, 2005

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Abstract

This document describes the evaluation of two standard electrical cable tray sizes, one junction box and two electrical cable air drops, all protected with the Hemyc One Hour Electrical Raceway Fire Barrier System (either directly attached or with a 2" stand-off), when exposed to the ASTM E119 time-temperature heating curve for a period of one hour. Results are given in the Conclusion Section of this report.

The details, procedures and observations reported herein are correct and true within the limits of sound engineering practice. All specimens and test sample assemblies were produced, installed and tested under the surveillance of either Sandia National Laboratories, the manufacturer's or the testing laboratory's in-house Quality Assurance Program. This report describes the analysis of a distinct assembly and includes descriptions of the test procedure followed, the assembly tested, and all results obtained.

Deggary N. Priest, President — April 18, 2005 Date

Reviewed and approved:

Constance A. Humphrey
QA Director — April 18, 2005 Date

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PURPOSE AND SCOPE

Note: This section has been reproduced in part from the Test Plan contained in Appendix A.

Section 50.48, "Fire Protection," of 10 CFR Part 50 requires that each operating nuclear power plant have a fire protection plan that satisfies General Design Criterion 3 of Appendix A to 10 CFR Part 50. Criterion 3 requires that structures, systems, and components important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions. Noncombustible and heat resistant materials shall be used wherever practical throughout the unit, particularly in locations such as the containment and control room. Fire detection and fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems, and components important to safety. Firefighting systems shall be designed to assure that their rupture or inadvertent operation does not significantly impair the safety capability of these structures, systems, and components. Section 50.48 also requires that all plants with operating licenses issued prior to January 1, 1979, satisfy the requirements of Sections III.G, III.J, and III.O of Appendix R to 10 CFR Part 50. (Post 1979 plants (per 10 CFR Part 50.48) have to comply with the provisions of their licenses.)

Section III.G of Appendix R, which addresses fire protection of safe shutdown capability, requires that fire protection features be provided such that one train of systems necessary to achieve hot shutdown conditions remains free of fire damage. One acceptable means of satisfying this requirement is to separate cables and equipment and associated non-safety circuits of redundant systems necessary to achieve and maintain hot shutdown conditions located in the same fire area by a fire barrier having a 3-hour fire rating (Section III.G.2.a). Another means is to enclose cables and equipment and associated non-safety circuits of one redundant train in a fire barrier having a 1-hour fire rating and install fire detectors and an automatic fire suppression system in the fire area (Section III.G.2.c).

The scope of this [project] is to describe the overall plan for investigating the fire resistance rating of [the] Hemyc (1-hour) … electrical raceway fire barrier system (ERFBS). The primary approach … [was] to perform [an] … ASTM E 119 furnace test on a number of electrical cable raceway types that [were] protected by … the Hemyc … fire barrier material. The Hemyc test [was] performed for a period of 60-minutes, followed by a hose stream test and post-test visual inspection of the ERFBS. . . .

OBJECTIVE

Note: This section has been reproduced in part from the Test Plan contained in Appendix A.

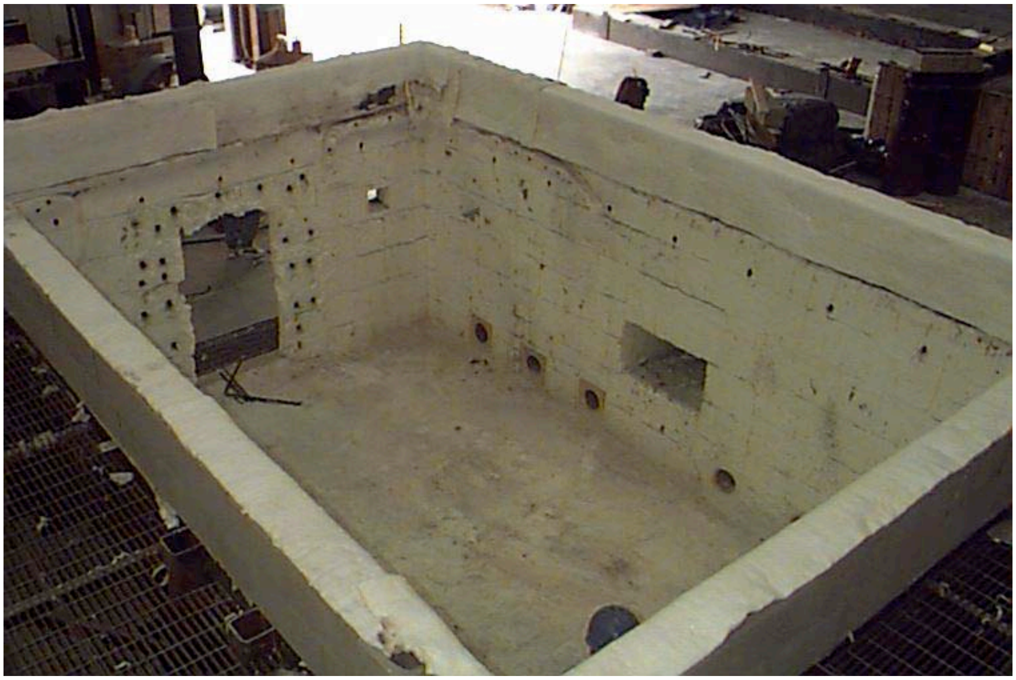
The objective of this program [was] to assess the fire resistance rating of Hemyc ERFBS by subjecting various test specimens (electrical cable trays, air drops and junction boxes) to standard temperature-time conditions as specified in ASTM E 119 and criterion stipulated in GL 86-10, Supplement 1. The types and characteristics of the ERFBS protecting the test specimens are intended to simulate as-installed configurations.

TEST PROCEDURE

Note: Since the Test Plan (Appendix A) includes an accurate and complete description of the test procedure to be followed, much of these details have not been reproduced in the main body of this report.

Horizontal Test Furnace

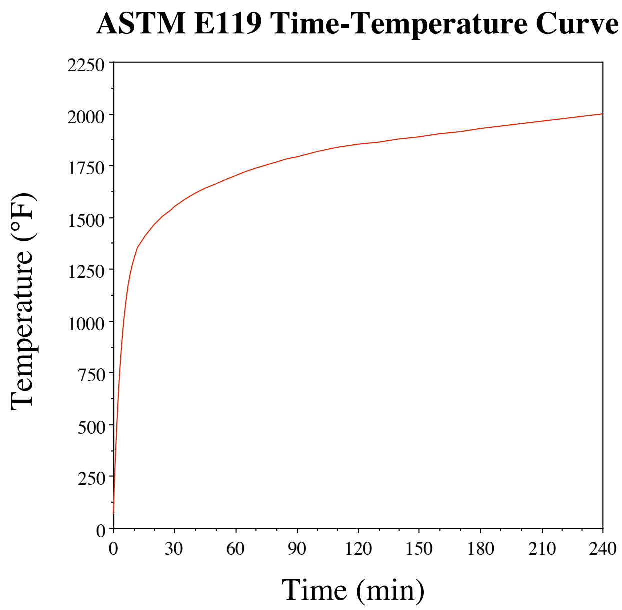
The 12' x 18' x 7' deep horizontal test furnace used in these evaluations was designed to allow the specimen to be uniformly exposed to the specified time-temperature conditions. It is fitted with 12 symmetrically-located premixed air/propane gas burners designed to allow an even heat flux distribution across the exposed surface of a horizontal test specimen. Furnace pressures may be maintained at any value from +0.03" W.C. to -0.05" W.C. The furnace consists of a structural steel frame, lined with sheet metal and insulated with a six inch thick layer of ceramic fiber.



12' x 18' Horizontal Furnace (Overhead View)

The temperature within the furnace is determined to be the mathematical average of thermocouples located symmetrically within the furnace with half positioned twelve inches below the bottom surface of the test deck and the other half located 12" below the bottom of the test specimens. In this manner, an average exposure on the entire assembly can be determined by averaging the readings in real time and adjusting the average temperature to follow the standard time-temperature curve. The materials used in the construction of these thermocouples are those suggested in the E119 test standard. During the performance of a fire exposure test, the furnace temperatures are monitored at least every 15 seconds and displayed for the furnace operator to allow control along the specified time-temperature curve. All data is saved to hard disk at intervals of once per minute unless more often is requested.

The fire exposure is controlled to conform with the standard time-temperature curve shown in Figure 1, as determined by the tables below:



Time (min)	Temperature (°F)
0	68
5	1000
10	1300
20	1462
30	1550
60	1700
90	1792
120	1850
180	1925
240	2000

Figure 1 E119 Temperature Exposure

The furnace interior temperature during a test is controlled such that the area under the time-temperature curve is within 10% of the corresponding area under the standard time-temperature curve for 1 hour or less tests, 7.5% for those less than 2 hours and 5% for those tests of 2 hours or more duration.

Furnace Pressure

The pressure differential between the inside of the furnace (as measured approximately 12" below the exposed surface of the test support slab) and the laboratory ambient air was maintained at 0.00 inches of water column for the duration of the fire exposure test (after the first five minutes, during which furnace stabilization was achieved). This was achieved and controlled by adjusting the inside furnace pressure until slight puffs of intermittent flames extended through unused thermocouple probe holes in the sides of the furnace, indicating a very slight positive pressure at these locations.

Thermocouple Locations

All four electrical cable trays were instrumented with 24 GA. Type K glass/glass insulated thermocouples (Special Limits of Error: ±1.1°C) purchased with calibration certifications and lot traceability. The thermo-junctions were mechanically attached along the mid-height of each tray side rail by clamping them under the heads of #8x32 stainless steel machine bolts placed into holes drilled and threaded to receive them, spaced 6" o.c. Bare #8 AWG, multiple-strand copper conductors were instrumented with similar thermocouples attached every 6 inches along the wire's length. These thermocouples were attached by placing the thermo-junction in direct contact with the surface of the wire and crimping the junction to the copper wire with a copper Buchanan 2011S open end splice cap fastened in place with a Buchanan C-24 "pres-SURE" tool. The instrumented bare #8 AWG conductor was then secured in place along the bottom longitudinal centerline of the tray rungs with plastic cable ties.

Two electrical cable air drop systems were simulated using bare #8 AWG, multiple-strand copper conductors, instrumented with similar thermocouples, installed 6" o.c. and held in place with Buchanan 2011S open end splice caps.

The outer surfaces of the junction box were instrumented with 1/16" diameter Inconel® sheathed, 30 Ga. Type K thermocouples, to allow them to withstand the temperatures which may be experienced by their leads passing between the junction box and outside the heated area. These thermocouples were not purchased with calibration certificates, but instead were numbered and sent to Sandia National Laboratories, which performed a series of multi-temperature point calibrations of them. The results of these calibrations are presented in Appendix D, Quality Assurance.

See Appendix C Thermocouple Locations for exact locations of all test item thermocouples.

Data Acquisition Systems

The outputs of the thermocouples were monitored by 300 channel and 100 channel Yokogawa, Inc., Model Darwin Data Acquisition Units, driven by Macintosh computers. The furnace control thermocouples were monitored by a separate 100 channel Yokogawa, Inc. Model Darwin Data Acquisition Unit and Macintosh computer. The computers were programmed in LabVIEW 5.0 to send the commands to the data acquisition systems to sample the data input lines and to convert the raw data into a usable format (i.e., degrees Fahrenheit) for display on screen and storage as an ASCII tab-delimited text file. Those files were then, after the test, imported into MS Excel for tabular and graphical display.

Correction Factor

In accordance with ASTM E119, when the indicated resistance period is $^{1}/_{2}$ h or over, determined by the average or maximum temperature rise on the unexposed surface or within the test sample, or by failure under load, a correction shall be applied for variation of the furnace exposure from that prescribed, where it will affect the classification, by multiplying the indicated period by two thirds of the difference in area between the curve of average furnace temperature and the standard curve for the first three fourths of the period and dividing the product by the area between the standard curve and a base line of 68°F (20°C) for the same part of the indicated period, the latter area increased by 3240°F•min to compensate for the thermal lag of the furnace thermocouples during the first part of the test. For a fire exposure in the test higher than standard, the indicated resistance period shall be increased by the amount of the correction. For a fire exposure in the test lower than standard, the indicated resistance period shall be similarly decreased for fire exposure below standard. The correction is accomplished by mathematically adding the correction factor, C, to the indicated resistance period.

The correction can be expressed by the following equation:

$$C = \frac{2I(A - A_s)}{3(A_s + L)}$$

where:

C = correction in the same units as *I*,
I = indicated fire-resistance period,
A = area under the curve of indicated average furnace temperature for the first three fourths of the indicated period,
A_s = area under the standard furnace curve for the same part of the indicated period, and
L = lag correction in the same units as *A* and A_s (54°F•h or 30°C•h (3240°F•min or 1800°C•min))

Hose Stream Test

Immediately following the fire endurance test, a hose stream test was performed in accordance with USNRC Generic Letter 86-10, Supplement 1, Enclosure 1, Section VI. The hose stream was "applied at random to all exposed surfaces of the test specimen through a 1-1/2" fog nozzle set at a discharge angle of 15 degrees with a nozzle pressure of not less than 75 psi and a minimum discharge rate of 75 gpm with the tip of the nozzle at a maximum of 10 feet from the test specimen. Duration of the hose stream application is 5 minutes." Prior to the hose stream application, the laboratory ensured the correct angle spray pattern, pressure and flow was achieved through calibrated gauges and other equipment as required.

Assessment Criteria

The test specimens were subjected to the ASTM E 119 temperature-time profile in the test furnace. An assessment of the ERFBS performance was based on two principal factors, as stated in Generic Letter 86-10, Supplement 1:

1. *The time at which the average unexposed side temperature of the fire barrier system, as measured on the exterior surface of the raceway or component, exceeds 139° C (250° F) above its initial temperature. Or the time at which a single temperature reading of a test specimen exceeds 30% of the maximum allowable temperature rise (i.e., 180° C [325° F]) above its initial temperature.*
2. *The fire barrier system remains intact during the fire exposure and water hose stream test without developing any openings through which the cable raceway is visible.*

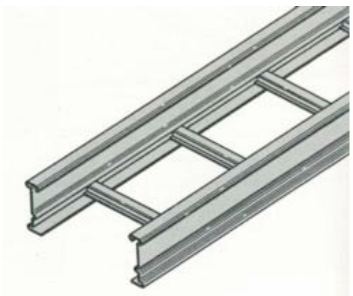
TEST SPECIMEN CONSTRUCTION

Supporting Deck

A 13' x 19' insulated 10 GA. steel deck was designed to accept the test items in this project. The deck was continuously welded and reinforced with 4" structural steel channel, as indicated in the drawings in Appendix B. The placement of all test items in the deck was adjusted to maximize distances between items and between items and furnace walls, and to minimize shadowing effects between items.

Each of the electrical cable trays were designed to pass through the test deck, extend 36" below the insulated lower surface of the deck, turn 90° (through a zero radius turn) to horizontal, extend a total of 60", and then turn 90° upwards (through a sweeping, 12" radius turn) and pass back up and through the supporting deck. The electrical cable air drops were designed to pass through the test deck, extend 36" below the deck insulation, then turn and pass back up and through the supporting deck. There was a 24" separation between the vertical legs of each electrical cable air drop assembly.

All test items were supported by structural elements on the unexposed side of the test deck at distances of 12" and 30" above the deck. No supports were used inside the furnace for the electrical cable trays. The junction box was held in place inside the furnace by a pair of "trapeze" supports, made of Unistrut that was wrapped in 2" thick Kaowool blankets. These blankets were secured to the support members by tape. The junction box, protected by Hemyc ERFBS, was mounted on the wrapped supports and secured by metal bands. Each of the electrical cable air drops was supported at its mid-point by a pair of metal bands secured to the test deck.



The weight of each side rail for the straight tray sections was 1.17 lbs/ft. The tray was constructed of pre-galvanized rails and rungs.

Each 4" x 12" galvanized steel tray system consisted of a 4" x 12" ladderback tray with 9" rung spacing (B-Line Systems, Model 248P09-12-144). The maximum fill depth was 3" and the side rail thickness was 0.048". A straight section passed down through the test deck for a minimum distance of 36", transitioned through a zero-degree radius bend (B-Line Systems, Model 9P8024) into a horizontal section of similar tray, and then transitioned through a sweeping (12" radius) 90° bend (B-Line Systems, Model 4P1290VI12) upwards into another straight section of tray which then passed up and through the test deck. The length of the horizontal section was 60" from vertical section to vertical section (inside dimensions).

Each 4" x 36" galvanized steel tray system consisted of a 4" x 36" ladderback tray with 9" rung spacing (B-Line Systems, Model 248P09-36-144). The maximum fill depth was 3" and the side rail thickness was 0.048". A straight section passed down through the test deck for a minimum distance of 36", transitioned through a zero-degree radius bend (B-Line Systems, Model 9P8024) into a horizontal section of similar tray, and then transitioned through a sweeping (12" radius) 90° bend (B-Line Systems, Model 4P3690VI12) upwards into another straight section of tray which then passed up and through the test deck. The length of the horizontal section was 60" from vertical section to vertical section (internal dimensions).

Raceway	Raceway Weight Per Unit Length (lb/ft)
2A (12" Tray)	3.05
2B (12" Tray)	3.05
2C (36" Tray)	4.07
2D (36" Tray)	4.07
2E (Air Drop)	0.43
2F (Air Drop)	0.48
2G (Junction Box)	26.07 lb

The weights of each raceway were determined prior to mounting them in the deck. Knowing their lengths, the weights per unit length were then calculated.

The Junction box weight is reported as a single item.

CONDUCT OF TEST

Preburn Inspections

As required in the Test Plan, prior to the commencement of the fire endurance test, a thorough check of the test assembly and associated equipment (including calibration of the data recording equipment) and completion of applicable Laboratory QA/QC checklists were performed and documented by the testing laboratory.

Written approval of the construction, assembly, installation and instrumentation was supplied by OPL and signed by Sandia National Laboratories' representative prior to performance of the fire exposure test (a sign-off sheet for this purpose was supplied by the Laboratory).

The test assembly was then placed on the large scale horizontal fire resistance furnace and the thermocouples connected to the data acquisition system and their outputs verified. The test assembly was inspected one last time before the furnace was closed prior to the test. Upon receipt of approval to proceed, the test was initiated. Following the fire exposure test, all data acquisition systems were recalibrated in accordance with the Test Plan.

TEST RESULTS

The thermocouples were connected to the data acquisition systems and their outputs verified on March 24, 2005. The furnace was fired on March 25, 2005, and computer data collection of thermocouple data continued for 60 minutes. The ambient temperature at the start of the test was 73°F, with 89% relative humidity. The furnace was fired at 9:10 AM and the standard time-temperature curve followed for 60 minutes. The pressure differential between the inside of the furnace (as measured 12" below the exposed surface of the test slab) and the laboratory ambient air was maintained at 0.00 inches of water column for the duration of the fire exposure test (after the first five minutes, during which furnace stabilization was achieved).

Persons present to perform or witness the test were as follows:

Deggary Priest	-	Omega Point Laboratories, Inc.
Connie Humphrey	-	Omega Point Laboratories, Inc.
Mike Dey	-	Omega Point Laboratories, Inc.
Cleda Patton	-	Omega Point Laboratories, Inc.
Troy Bronstad	-	Omega Point Laboratories, Inc.
Oscar Estrada	-	Omega Point Laboratories, Inc.
Richard Beasley	-	Omega Point Laboratories, Inc.
Laudencio Castanon	-	Omega Point Laboratories, Inc.
Frank Wyant	-	Sandia National Laboratories
Bruce Levin	-	Sandia National Laboratories
Charles Girard	-	URS Corporation (SNL contractor)
David Lew	-	US Nuclear Regulatory Commission
Mark Salley	-	US Nuclear Regulatory Commission
Roy Woods	-	US Nuclear Regulatory Commission
Alex Klein	-	US Nuclear Regulatory Commission
Randy Brown	-	Promatec
Mike Jordan	-	Promatec
Frank Haese	-	Promatec

Observations made during the test were as follows:

TIME (h:min:s)	OBSERVATIONS
0:00	Furnace ignited at 9:10 AM.
1:30	Some smoke from the top seals on the deck. Tape on JB supports burning.
10:45	JB supports still flaming on the bottom.
12:00	Stitches on the seams are breaking along the sweeping 90° elbow on Item 2B.
28:00	JB supports till flaming on bottom.
60:00	Furnace extinguished. Specimen thermocouples were disconnected and the test assembly lifted from the furnace, observed, photographed and moved to the hose stream test area. The test items with obvious openings included: 2A, 2C, 2E, and 2G.
1:06:49	Hose stream began at a nozzle spray angle of 15°, pressure at 75 psi and from a distance of 10 ft. The entire test assembly was slowly spun and the hose stream operator remained stationary and applied the hose to the test items as they passed in front of him.
1:11:49	Hose stream stopped. The test assembly was then observed, photographed and allowed to drip for several hours before being placed on 8' tall 24" ø pipe stands and undergoing post-test disassembly. There were no significant changes in any of the exterior claddings on the raceways due to the hose stream test.

Observations made after the hose stream test.

Test Item	Observation
2A	Edge joints open on horizontal and vertical sides around zero radius bend.
2B	No significant openings.
2C	Openings around circumferential joint through which the raceway could be seen.
2D	One opening at inside of sweeping 90° elbow, some torn outer fabric.
2E	Openings around circumferential joint through which the raceway could be seen.
2F	No openings.
2G	Openings along edge joints.

Other than small pieces of the deck insulation falling to the laboratory floor, the test assembly showed no visible effect due to the hose stream test. Much steam and dripping hot water remained after the hose stream was stopped.

In accordance with the E119 test standard, a calculation for any correction to the indicated fire resistance period was done. The correction factor was then mathematically added to the indicated fire resistance period, yielding the fire resistance period achieved by this specimen:

ITEM	DESCRIPTION	TEST VALUE
C	correction factor	0.02 min (1 second)
I	indicated fire-resistance period	60 min
A	area under the curve of indicated average furnace temperature for the first three fourths of the indicated period	58 542°F • min
As	area under the standard furnace curve for the same part of the indicated period	58 516°F • min
L	lag correction	3240°F • min
	FIRE RESISTANCE EXPOSURE RECEIVED BY THIS SPECIMEN ==>	60

Note: The standard specifies that the fire resistance be determined to the nearest integral minute. Consequently, if the correction factor is less than 30 seconds, and the test specimen met the criteria for the full indicated fire resistance period, no correction is deemed necessary. That was the case for this project.

CONCLUSIONS

In accordance with the assessment criteria listed in the Test Plan, all raceway systems failed to meet a 1h fire endurance period. The table below summarizes the results for each item.

Raceway	Right Rail Time to $\Delta T_{avg} \geq$ 250°F (min)	Right Rail Time to $\Delta T_{ind} >$ 325°F (min)	Left Rail Time to $\Delta T_{avg} \geq$ 250°F (min)	Left Rail Time to $\Delta T_{ind} >$ 325°F (min)	Bare #8 Time to $\Delta T_{avg} \geq$ 250°F (min)	Bare #8 Time to $\Delta T_{ind} >$ 325°F (min)	Max. Temp. Bare #8 @ 1h (F)	Burn-Through/ Structural Failure Yes/No	Pass Hose Stream Yes/ No	Final Grade Pass/ Fail
2A: 12" Tray (Direct Attach.)	36	34	27	18	32	32	1260	Yes	No	Fail
2B: 12" Tray (w/2" air gap)	37	35	38	35	33	40	1002	No	Yes	Fail
2C: 36" Tray (Direct Attach.)	41	39	34	33	35	35	1330	Yes	No	Fail
2D: 36" Tray (w/2" air gap)	32	31	33	32	28	27	1117	Yes	No	Fail
2E: Air Drop (Direct Attach.)	-	-	-	-	35	32	1712	Yes	No	Fail
2F: Air Drop (w/2" air gap)	-	-	-	-	32	28	1411	No	Yes	Fail
2G: Junct. Box (Direct Attach.)	31*	32*	-	-	-	-	n/a	Yes	No	Fail

Note: Due to the occurrences of openings in most of the tray systems, no significant increase in fire endurance due to the 2" air gap was observed. For the electrical cable air drops, the direct attachment (even with openings) performed better than the 2" air gap.

* Junction box temperatures were measured on the outside surfaces.